E86-10022

NASA-CR-175861

DAA/GODDARD

SQT

ETRS

ELEVENTH QUARTERLY REPORT

ON

"SPECTRORADIOMETERIC CALIBRATION OF THE THEMATIC MAPPER AND MULTISPECTRAL SCANNER SYSTEM"

Contract Number NAS5-27832

For the Period: 1 June 1985 through 31 August 1985

NASA/Goddard Space Flight Center

Greenbelt, Maryland 20771

Philip N. Slater, Principal Investigator

James M. Palmer, Co-Investigator

(E86-10022 NASA-CR-175861) SPECTRORADIOMETRIC CALIBRATION OF THE THEMATIC MAPPER AND MULTISPECTRAL SCANNER SYSTEM Quarterly Report, 1 Jun. - 31 Aug. 1985 (Arizona Univ., Tucson.) 18 p

HC A02/MF A01

N86-17816

Unclas

G3/43 00022

Optical Sciences Center

University of Arizona

Tucson, Arizona 85721

September 30, 1985

Introduction

This is the eleventh quarterly report on Contract NAS 5-27382 entitled "Spectroradiometric Calibration of the Thematic Mapper." Those involved in the program during this period were S. Biggar, M. C. Dinguirard, R. G. Holm, Y. Mao, J. M. Palmer, P. N. Slater, S. L. Witman and B. Yuan of the Optical Sciences Center, University of Arizona, R. D. Jackson and M. S. Moran of the Agricultural Research Service, United States Department of Agriculture, D. Ferralez and R. K. Savage of the Atmospheric Sciences Laboratory, White Sands Missile Range.

Calibrations at White Sands on October 28, 1984 and May 24, 1985

The previous quarterly report described the results of the October 28, 1984 calibration at White Sands. Since then we have attempted to standardize our presentation of the results and these are shown in Tables 1 and 2 and in Figure 1. Table 1 is a summary of all the critical values used in the final steps of the data reduction and the comparison of the results with the pre-flight and internal calibrator (IC) data. Suggestions regarding the format and the data to be included in future summaries will be welcomed. Table 2 is a listing of the case for a Rayleigh atmosphere.

Figure 1 is a bar graph which conveniently compares the various results. The "Preflight" and "IC" values make use of the TM digital counts for our site in conjunction with the appropriate gains and offsets obtained from John Barker's TRAPP reports. The "Code" value corresponds to our determination of the spectral

TABLE 1

WHITE SANDS CALIBRATION OF THE THEMATIC MAPPER ON OCTOBER 28, 1984.

Solar zenith angle Z: 52.068	Latitude: 32 deg 55 min
Solar distance in AU: 0.9932	Longitude: 106 deg 22 min
Junge size distribution: 4.09	Elevation: 1196 m
Aerosol size range: 0.02 to 5.02 um	Pressure: 663.7 mm
Refractive index: 1.54 - 0.01i	Temperature: 12.4 deg C
Time of overpass: 10:09.1 MST	Relative humidity: 75%

Thematic Mapper bands	1	2	3	4
Central wavelength um	0.4863	0.5706	0.6607	0.8382
Tau Mie	0.1360	0.1027	0.0750	0.0401
Tau Rayleigh	0.1420	0.0739	0.0407	0.0156
Tau ozone	0.0047	0.0198	0.0098	0.0011
Tau water vapor	0.0000	0.0000	0.0000	0.0454
Tau carbon dioxide	0.0000	0.0000	0.0000	0.0000
Spectral reflectance	0.4250	0.4830	0.5170	0.5590
Code for zenith angle of 45.00	0.0915	0.0985	0.1086	0.1471
Code for zenith angle of 55.00	0.0731	0.0782	0.0867	0.0861
Eo across band in W/m2.um	1955.5	1826.9	1545.0	1042.8
Image digital counts	223.25	169.00	161.31	150.50
Preflight cal gains	15.553	7.860	10.203	10.821
Preflight cal offsets	1.8331	1.6896	1.8850	2.2373
IC cal gains for 28 Oct 84	14.211	7.264	9.551	10.427
IC cal offsets for 28 Oct 84	2.2570	2.2160	2.3700	2.3640
Normalized code for Z = 52.068	0.0784	0.0842	0.0931	0.1040
Code TM L in W/m2.sr.um	155.51	155.87	145.79	109.96
Spectral L from preflight cal	142.36	212.86	156.25	137.01
Spectral L from IC cal	155.51	229.60	166.41	142.07
% (Code-Pre)/Pre	9.2	-26.8	-6.7	-19.7
% (Code-IC)/IC	.0	-32.1	-12.4	-22.6

****

TABLE 2

WHITE SANDS CALIBRATION OF THE THEMATIC MAPPER ON OCTOBER 28, 1984,

ASSUMING A RAYLEIGH ATMOSPHERE.

Solar zenith angle Z: 52.068	Latitude: 32 deg 55 min
Solar distance in AU: 0.9932	Longitude: 106 deg 22 min
Junge size distribution: 4.09	Elevation: 1196 m
Aerosol size range: 0.02 to 5.02 um	Pressure: 663.7 mm
Refractive index: 1.54 - 0.01i	Temperature: 12.4 deg C
Time of overpass: 10:09.1 MST	Relative humidity: 75%

Thematic Mapper bands	1	2	3	4
Central wavelength um	0.4863	0.5706	0.6607	0.8382
Tau Rayleigh	0.1420	0.0739	0.0407	0.0156
Spectral reflectance	0.4250	0.4830	0.5170	0.5590
Code for zenith angle of 45.00	0.0981	0.1095	0.1167	0.1259
Code for zenith angle of 55.00	0.0791	0.0884	0.0944	0.1020
Eo across band in W/m2.um	1955.5	1826.9	1545.0	1042.8
Image digital counts	223.25	169.00	161.31	150.50
Preflight cal gains	15.553	7.860	10.203	10.821
Preflight cal offsets	1.8331	1.6896	1.8850	2.2373
IC cal gains for 28 Oct 84	14.211	7.264	9.551	10.427
IC cal offsets for 28 Oct 84	2.2570	2.2160	2.3700	2.3640
Normalized code for Z = 52.068	0.0846	0.0946	0.1009	0.1090
Code TM L in W/m2.sr.um	167.78	175.17	158.05	115.25
Spectral L from preflight cal	142.36	212.86	156.25	137.01
Spectral L from IC cal	155.51	229.60	166.41	142.07
% (Code-Pre)/Pre	17.9	-17.7	1.2	-15.9
% (Code-IC)/IC	7.9	-23.7	-5.0	-18.9

****

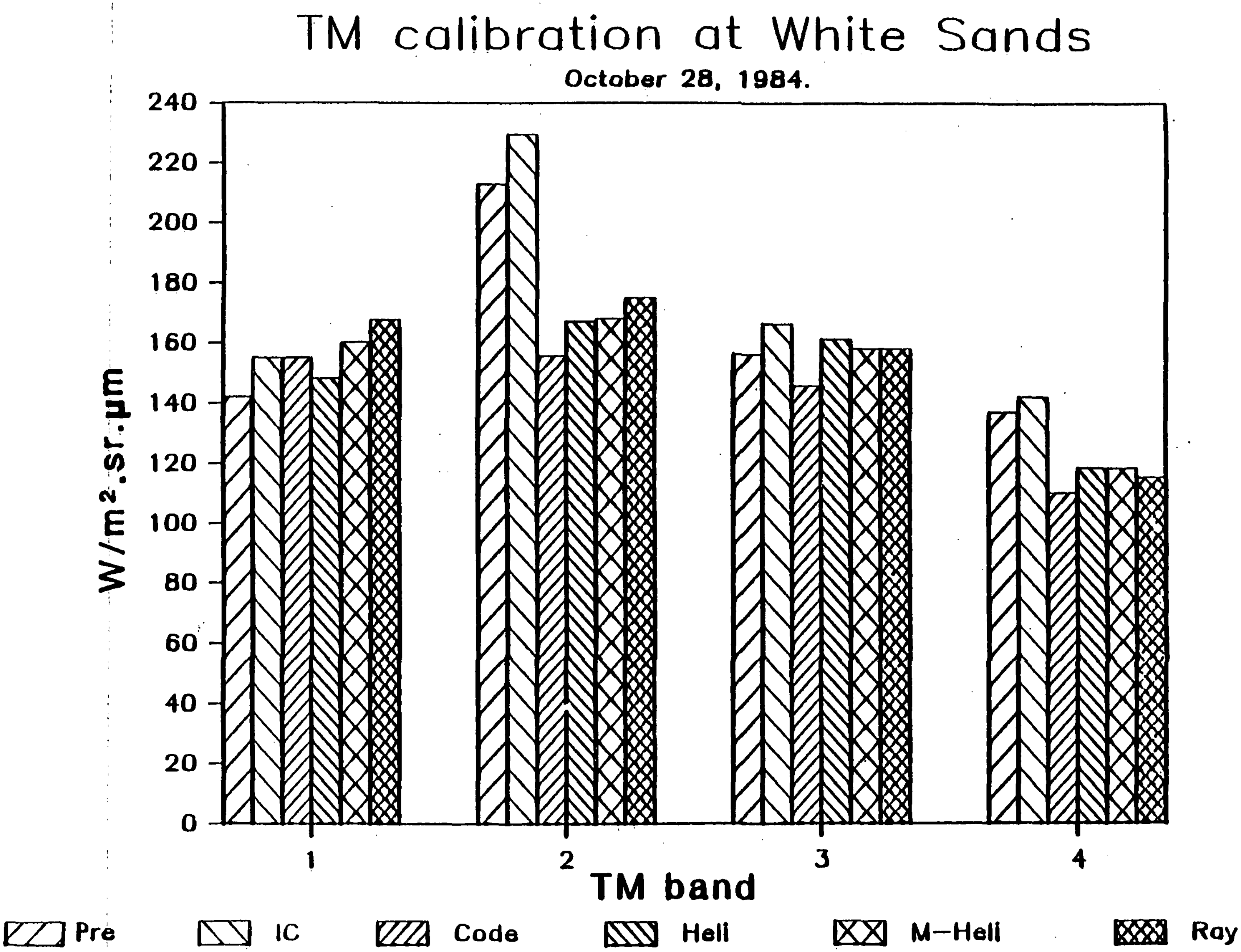

TM calibration at White Sands
October 28, 1984.
240
220
200
180
160
140
120
100
80
60
40
20
0
W/m².sr.µm
1
2
3
4
TM band
Pre
IC
Code
Hell
M—Hell
Ray

Figure 1.

radiance at TM as obtained on the basis of ground spectral reflectance measurements, atmospheric measurements and the use of the Herman radiative transfer code. The 'Heli' values are obtained from absolute spectral radiance measurements made from a helicopter-mounted spectropolarimeter at 10,000 ft. ASL (6,000 ft. AGL) and corrected for the atmosphere above 10,000 ft., see the following section. The 'Heli-M' values are modified 'Heli' values. The 'Heli' values and the atmospheric values were assumed correct and the ground reflectance values were changed so that the Herman code gave exactly the helicopter radiance values. The radiance values at the TM were then calculated on this basis. The Rayleigh atmosphere values were calculated for comparison purposes. It is worth noting that, for the observational conditions at White Sands, the results for no atmosphere, or for a White Sands reflecting surface above the atmosphere, closely match the Rayleigh result. There is roughly a 2% difference in TM band 1, a 1% difference in TM band 2 and less than a 1% difference in other bands.

Figure 1 displays at a glance the discrepancies between the TM calibration data and our results for bands 2 and 4. We have not yet found a satisfactory explanation for the discrepancies. It is our belief that our predicted results and the TM calibration gains and offsets are correct. We are therefore looking for a source of additional radiance that is both spectrally and temporally varying. Three speculations are as follows:

1. The local atmosphere surrounding the spacecraft luminesced in bands 2 and 4 due to strong solar UV irradiation. This local atmosphere is assumed to change in density and composition following the use of the 'orbit adjust' jets. An orbital adjustment was made in September 1984.

2. William Clark and Donald Novak (CSC) have commented that Landsat-5 Control Simulation Facility staff have recently noted occasional unanticipated decelerations in the S/C velocity. These periods of deceleration seem to coincide with the locations of previous orbital adjustments. An explanation advanced is that a cloud of burnt hydrozine gas, presumably oxides of nitrogen, remains at these locations and causes additional drag when the S/C encounters them. This unlikely explanation could be used together with (1) above, although ionization of the gas cloud induced by transit of the S/C through it is another possibility.

3. Experiments were conducted in March, August and September 1984 in which barium and/or lithium were injected into the upper atmosphere. These substances are ionized by solar UV radiation and could give rise to the additional radiance recorded.

These three hypotheses are extremely tentative and will be investigated in detail in the following weeks. In addition, John Barker has agreed to estimate the radiance in the TM bands using CCTs at his disposal. If his and our values agree, then this will remove other possible error sources--of receiving the wrong tape or incorrectly reading it, or applying the wrong gain and offset values.

The calibration results for May 24, 1985 are tabulated in Tables 3 and 4 and diagrammed in Figure 2. Unfortunately no helicopter data were collected. This was because the steps from all helicopters were ordered removed because they had not been certified air worthy. As the spectropolarimeter was hard mounted to a

TABLE 3

WHITE SANDS CALIBRATION OF THE THEMATIC MAPPER ON MAY 24, 1985.

Solar zenith angle Z: 27.81	Latitude: 32 deg 55 min
Solar distance in AU: 1.0127	Longitude: 106 deg 22 min
Junge size distribution nu: 3.39	Elevation: 1196 m
Aerosol size range: 0.02 to 5.02 um	Pressure: 661.0 mm
Refractive index: 1.54 - 0.01i	Temperature: 26.7 deg C
Time of overpass: 10:09.2 MST	Relative humidity: 35%

Thematic Mapper bands	1	2	3	4
Central wavelength um	0.4863	0.5706	0.6607	0.8382
Tau Mie	0.1392	0.0959	0.0775	0.0708
Tau Rayleigh	0.1418	0.0734	0.0405	0.0155
Tau ozone	0.0090	0.0380	0.0186	0.0022
Tau water vapor	0.0000	0.0000	0.0000	0.0454
Spectral reflectance	0.449	0.495	0.538	0.575
Code for zenith angle of 25.00	0.1270	0.1306	0.1476	0.1471
Code for zenith angle of 35.00	0.1138	0.1168	0.1325	0.1317
Eo across band in W/m2.um	1955.5	1826.9	1545.0	1042.8
Image digital counts	>255.00	190.56	222.88	187.90
Preflight cal gains	15.553	7.860	10.203	10.821
Preflight cal offsets	1.8331	1.6896	1.8850	2.2373
IC cal gains for 28 Oct 84	14.2110	7.2640	9.5510	10.4270
IC cal offsets for 28 Oct 84	2.2570	2.2160	2.3700	2.3640
Normalized code for Z = 27.810	0.1233	0.1267	0.1433	0.1428
Code TM L in W/m2.sr.um	235.09	225.66	215.95	145.18
Spectral L from preflight cal		240.29	216.60	171.58
Spectral L from IC cal		259.28	230.88	177.94
% (Code-Pre)/Pre		-6.1	-0.3	-15.4
% (Code-IC)/IC		-13.0	-6.5	-18.4

****

TABLE 4

WHITE SANDS CALIBRATION OF THE THEMATIC MAPPER ON MAY 24, 1985.

ASSUMING A RAYLEIGH ATMOSPHERE.

Solar zenith angle Z: 27.81	Latitude: 32 deg 55 min
Solar distance in AU: 1.0127	Longitude: 106 deg 22 min
Junge size distribution nu: 3.39	Altitude: 1196 m
Aerosol size range: 0.02 to 5.02 um	Pressure: 661.0 mm
Refractive index: 1.54 - 0.01i	Temperature: 26.7 deg C
Time of overpass: 10:09.2 MST	Relative humidity: 35%

Thematic Mapper bands	1	2	3	4
Central wavelength um	0.4863	0.5706	0.6607	0.8382
Tau Rayleigh	0.1418	0.0734	0.0405	0.0155
Spectral reflectance	0.449	0.495	0.538	0.575
Code for zenith angle of 25.00	0.1335	0.1447	0.1563	0.1663
Code for zenith angle of 35.00	0.1201	0.1304	0.1410	0.1502
Eo across band in W/m2.um	1955.5	1826.9	1545.0	1042.8
Image digital counts	>255.00	190.56	222.88	187.90
Preflight cal gains	15.553	7.860	10.203	10.821
Preflight cal offsets	1.8331	1.6896	1.8850	2.2373
IC cal gains for 28 Oct 84	14.211	7.264	9.551	10.427
IC cal offsets for 28 Oct 84	2.2570	2.2160	2.3700	2.3640
Normalized code for Z = 27.810	0.1297	0.1407	0.1520	0.1618
Code TM L in W/m2.sr.um	247.34	250.63	228.93	164.51
Spectral L from preflight cal		240.29	216.60	171.58
Spectral L from IC cal		259.28	230.88	177.94
% (Code-Pre)/Pre		4.3	5.7	-4.1
% (Code-IC)/IC		-3.3	-0.8	-7.5

****

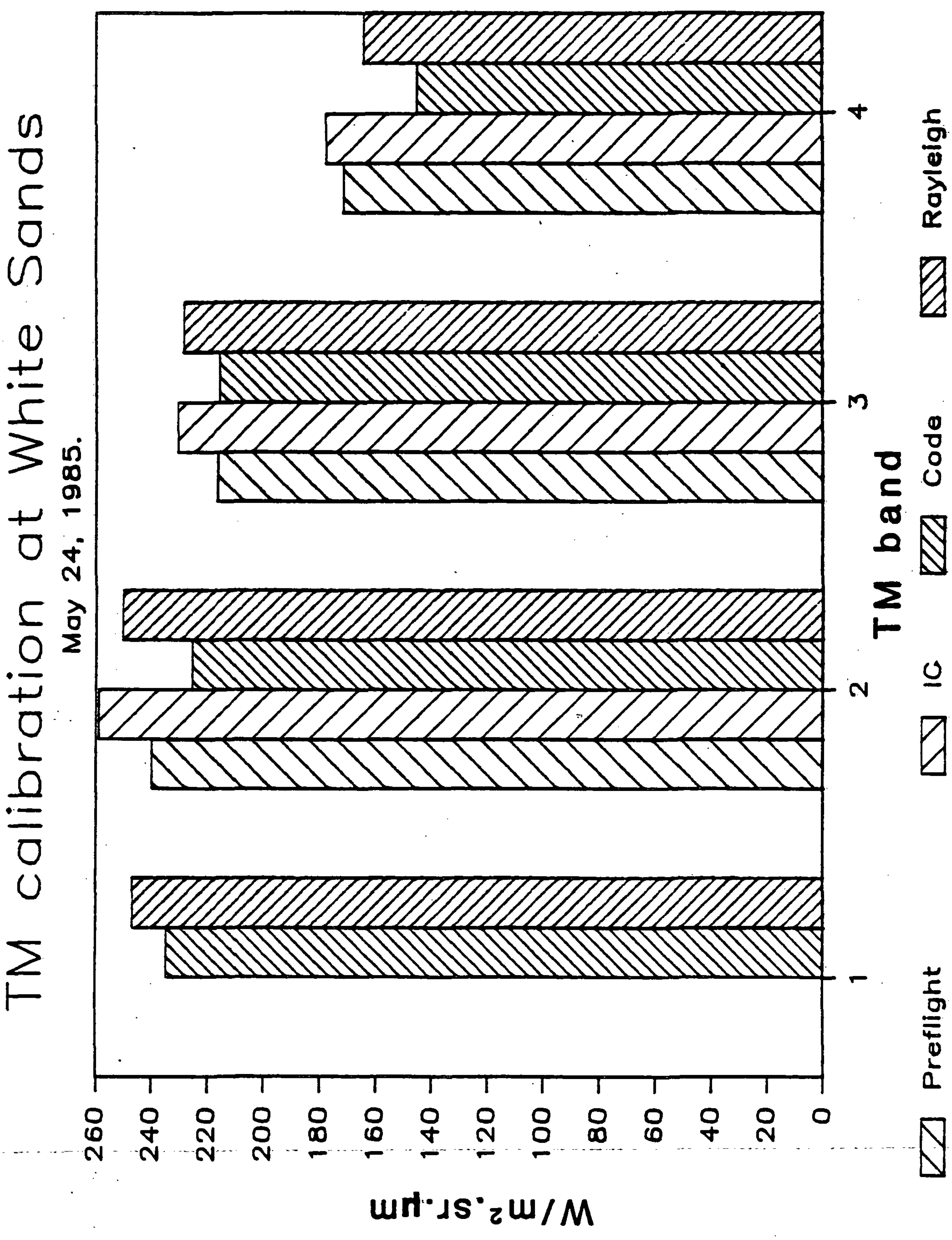

TM calibration at White Sands
May 24, 1985.
260
240
220
200
180
160
140
120
100
80
60
40
20
0
W/m².sr.µm
1
2
3
4
TM band
Preflight
IC
Code
Rayleigh

Figure 2.

step, it meant we had to have a new mount designed, built and certified.*

Like the October 28, 1984 results, the May 24, 1985 bar graphs show that the Rayleigh atmosphere gives greater radiance at TM than the Code. This is to be expected because, for high reflectance, an increase in atmospheric turbidity causes a decrease in the total radiance leaving the atmosphere. No update on the IC gains and offsets has been received, so the gains and offsets obtained for October 28, 1984 were used for May 24, 1985.

The Use of Ground and Intermediate Altitude Radiance Data

Until October 28, 1984, we had relied entirely on the originally proposed calibration method based on reflectance factor measurements. Highly accurate absolute reflectance measurements are difficult to make, particularly in the field. To provide a check on our measurements, we decided to complement them with ground radiance measurements from ground level and helicopter altitudes with an absolutely calibrated spectroradiometer and spectropolarimeter. The drawbacks to this method are first the hostile environment of a helicopter and second the difficulty in precisely knowing the area measured. To overcome the latter, we have

---

*Unfortunately this cost money and took excessive time. The certification from St. Louis was not received until 26 September 1985. For this reason, the helicopter flight for August 27, 1985 in conjunction with NOAA aircraft flights and the VISSR and AVHRR overpasses was cancelled. The following day, the maintenance supervisor for the helicopters at Holloman Air Force Base gave us permission to fly the instrument in a temporary mount and this was used for the flights of August 28, 1985 coincident with TM, and August 29, 1985 coincident with VISSR and NOAA Lear Jet overflights at 40,000 ft and 2,000 ft.

boresighted a 35 mm camera with the spectropolarimeter and synchronized the operation of the two. The helicopter measurement can more accurately simulate the space measurement and average the radiance over an area of one TM pixel or more. In addition, the photography of the ground site can provide a convenient and accurate way to map the ground reflectance. However, this technique has not yet been satisfactorily reduced to practice. Until it is, we rely entirely on an alternative ground reflectance measurement method which involves carrying a Barnes MMR by yoke for about a kilometer across a marked ground pattern.

In analyzing the results from the intermediate altitude measurements, we noticed a surprising independence of the data with altitude. Computer simulations were made for intermediate altitudes from 0 to 70,000 ft for ground reflectance values of 0, 0.1, 0.25, 0.5 and 1.0, for the atmospheric conditions of October 28, 1984 and for a solar zenith angle of 35°. The results are shown in Figures 3-6 and confirm our initial observations that radiances at intermediate altitudes very closely approximate those at the top of the atmosphere for reflectances in the vicinity of 0.5. (Note that on the ordinate, L_s is the total radiance above the atmosphere and L_H is the total radiance at an intermediate altitude.) The explanation for this can be found from the basic remote sensing equation:

$$L_s = \frac{E_g \rho \tau}{\pi} + L_p$$

where L_s is the total radiance at the sensor,

E_g is the ground irradiance,

L_ρ is the path radiance,

τ is the atmospheric transmittance,

ρ is the ground reflectance.

In the low ρ case, the radiance L_s at high altitude is greater than that at low altitude, the L_p term is larger than the $\frac{E_g \rho \tau}{\pi}$ term and increases more rapidly with increasing altitude than the $\frac{E_g \rho \tau}{\pi}$ term decreases. For high reflectance, the opposite is the case. The $\frac{E_g \rho \tau}{\pi}$ term is larger than the L_p term, then as the altitude becomes larger τ decreases and the effect is that the $\frac{E_g \rho \tau}{\pi}$ term decreases more rapidly than the L_p term increases. This givens rise to a decrease in L_s with increasing altitude for high reflectances. For an intermediate reflectance value, the change of L_s with altitude is nearly zero and therefore the radiance measured at the ground is the same as that measured from space. For cases where L_p is always small compared to $\frac{E_g \rho \tau}{\pi}$, as it is for TM bands 5 and 7, the high ρ case described above pertains.

An important conclusion that can be drawn from Figures 3-8 is that: <u>measuring the radiance of the ground at ground level and/or from intermediate altitudes at White Sands gives an approximate and in some cases an accurate direct measure of the radiance as measured from space</u>. Furthermore, if the wavelength, reflectance or atmospheric conditions are not quite appropriate, the small correction necessary can be made accurately. Further analyses are being made of this method for sea level targets and more turbid atmospheres than at White Sands to see if, under these

Figure 3.
Wavelength = 0.4863 μm, solar zenith angle = 35°.
Tau_M = 0.136, tau_R = 0.142, tau_{Oz} = 0.0047.
Junge radial size distribution, ν = 4.09.
Aerosol size range 0.02 to 5.02 μm in 0.04 μm steps. Refractive index = 1.54 - 0.01i.
Conditions are for White Sands, NM, on October 28, 1984.

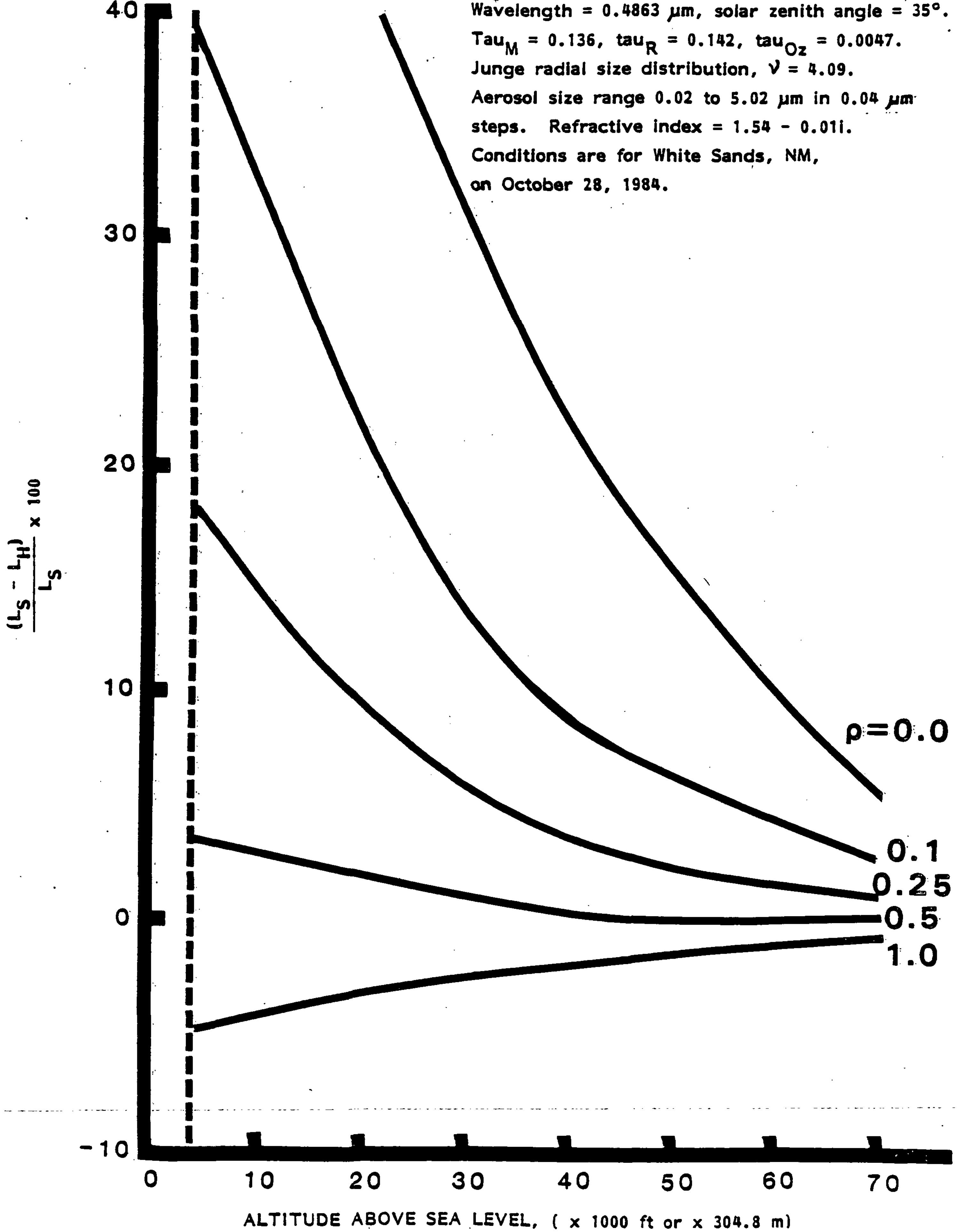
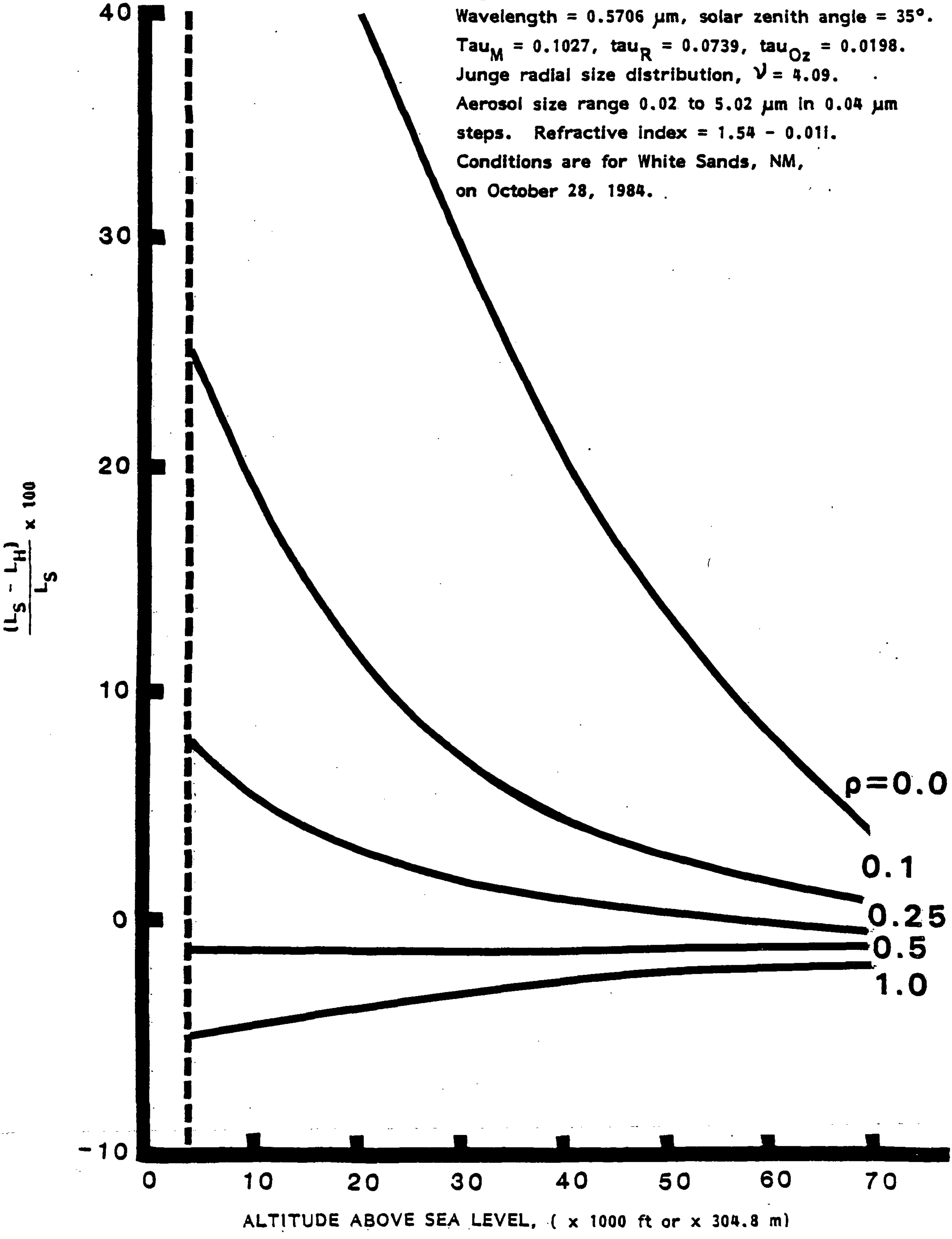


Figure 4.
Wavelength = 0.5706 μm, solar zenith angle = 35°.
Tau_M = 0.1027, tau_R = 0.0739, tau_{Oz} = 0.0198.
Junge radial size distribution, ν = 4.09.
Aerosol size range 0.02 to 5.02 μm in 0.04 μm steps. Refractive index = 1.54 - 0.01i.
Conditions are for White Sands, NM, on October 28, 1984.



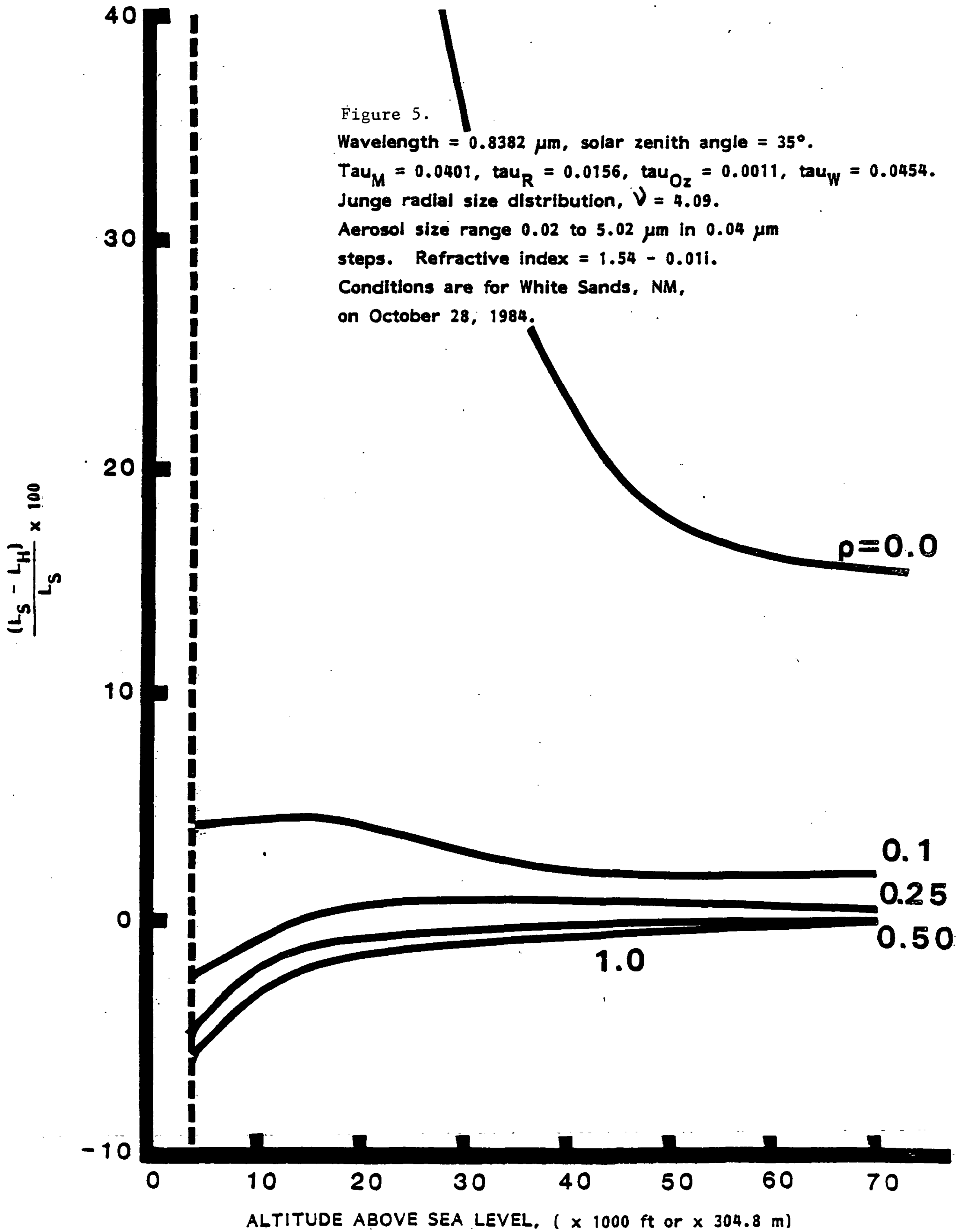


Figure 5.
Wavelength = 0.8382 μm, solar zenith angle = 35°.
Tau_M = 0.0401, tau_R = 0.0156, tau_{Oz} = 0.0011, tau_W = 0.0454.
Junge radial size distribution, ν = 4.09.
Aerosol size range 0.02 to 5.02 μm in 0.04 μm steps. Refractive index = 1.54 - 0.01i.
Conditions are for White Sands, NM, on October 28, 1984.

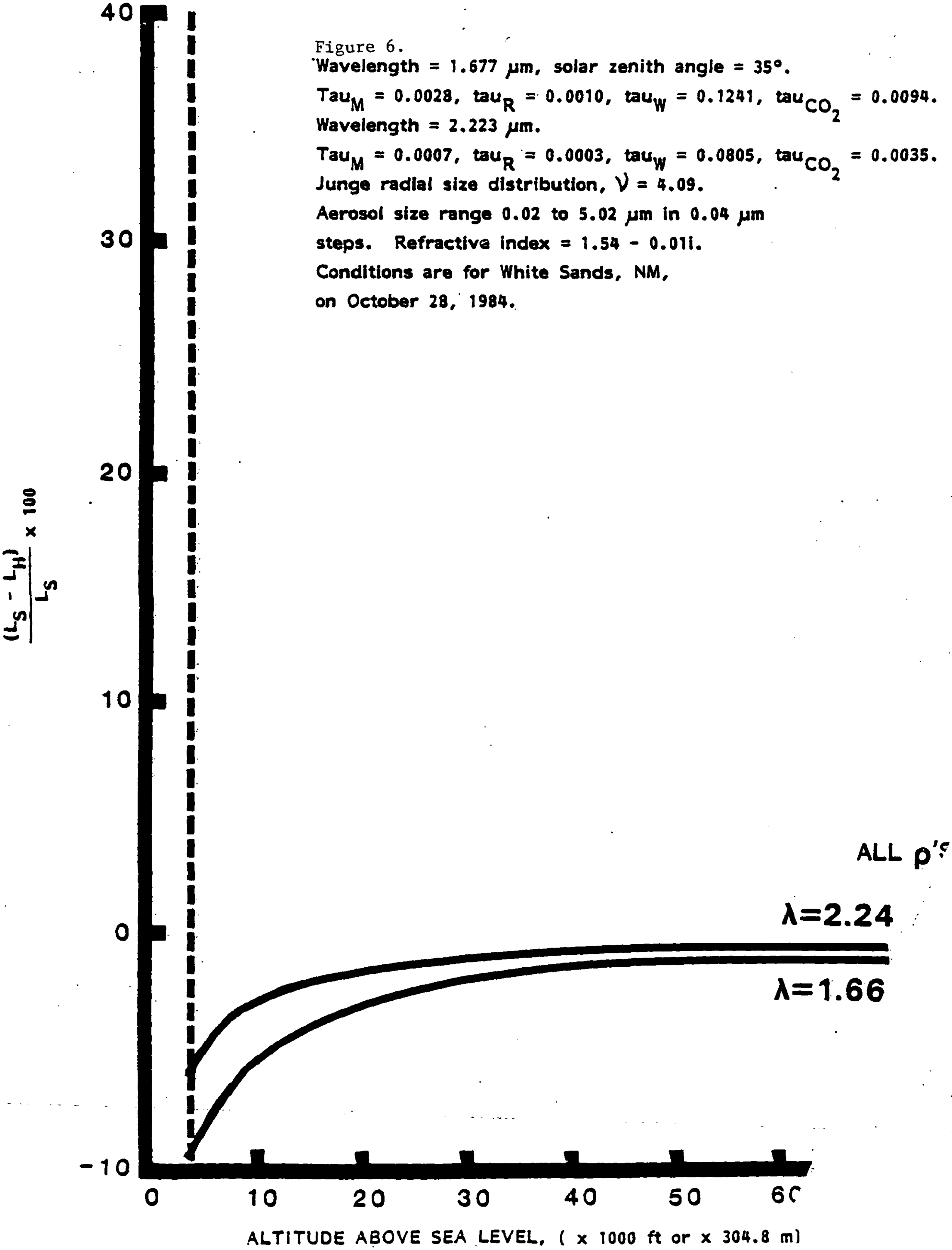


Figure 6.
Wavelength = 1.677 μm, solar zenith angle = 35°.
Tau_M = 0.0028, tau_R = 0.0010, tau_W = 0.1241, tau_{CO_2} = 0.0094.
Wavelength = 2.223 μm.
Tau_M = 0.0007, tau_R = 0.0003, tau_W = 0.0805, tau_{CO_2} = 0.0035.
Junge radial size distribution, ν = 4.09.
Aerosol size range 0.02 to 5.02 μm in 0.04 μm steps. Refractive index = 1.54 - 0.01i.
Conditions are for White Sands, NM, on October 28, 1984.

conditions, more commonly found lower reflectance sites yield the same results and could therefore be used conveniently for sensor calibration purposes.

The point that deserves repeating is that this method of radiance measurement provides an entirely independent check of the reflectance method for sensor calibration purposes. It depends on the accuracy to which a spectroradiometer can be calibrated in terms of radiance and used to measure the average radiance of an area of the ground sampled by the space sensor.

Current Activities

During the past summer, two more data sets were collected at White Sands and four were collected at Maricopa. These are presently being reduced and the results will be presented in the next quarterly report.

One of the data sets at White Sands includes measurements made on three consecutive days for AVHRR and VISSR as well as TM. An attempt was made to coordinate our ground and helicopter measurements with those from a Lear Jet and U-2 conducted by a NOAA team that included B. Fridovich, J. Krull and G. Smith. Although this was not entirely successful, e.g. see the earlier comment on lack of helicopter measurements on 27 August 1985, we were able to make a useful cross-comparison of sensor calibration with reference to the portable integrating sphere that NOAA uses to calibrate their flight instruments.

In every respect, this attempt at coordination with NOAA was worthwhile and we hope will provide a useful comparison between satellite sensors, aircraft and ground sensors and measurement methodologies. We plan to continue these kinds of cooperative measurements which scientists from NOAA and the Canada Centre for Remote Sensing.